The lunar crust

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English academic summary

Over the past 50 years, our knowledge of the Moon has grown immensely. Progress in lunar science occurred through several phases. The first phase happened in the 1960s and 70s, during the Apollo and Luna missions, with the study of samples returned from the lunar surface. Petrological characterisation of lunar samples sparked the Lunar Magma Ocean concept, from which ensued the traditional view of the lunar crust and mantle organisation: the crust is plagioclase-rich, and its mafic content increases with increasing depth. The lunar mantle is commonly thought to be olivine-rich, like that of the Earth. The second lunar exploration phase happened in the 1990s, when satellites were launched into lunar orbit, collecting the first global remote sensing datasets. Owing to their wide to global coverage, remote sensing brought new insight into lunar science that is complementary to that provided by lunar samples. During the third, current phase of lunar exploration, new datasets were collected by spacecrafts orbiting the Moon between the 2000s and today. The remote sensing datasets acquired during the second and third phases of lunar exploration progressively complicated the initially simple picture that scientists drew from earlier studies. Indeed, high resolution remote sensing images and radar data led to the identification of volcanic features (domes, irregular mare patches), and the unambiguous discovery of volatiles in permanently shadowed regions and in lunar samples originating at depth in the Moon, demonstrating the Moon's complex geological history.

During this PhD, impact craters were used as natural drill holes through the lunar crust to sample material located underneath the surface. During impact, rocks from depth are emplaced in crater central peaks through elastic rebound, making it possible to investigate the composition of the crust at depth. Spectroscopic data from Chandrayaan-1's Moon Mineralogy Mapper instrument were exploited to gather information on the composition of the crust in those central peaks.

In chapter 1, we present an algorithm for processing Moon Mineralogy Mapper spectroscopic data. The algorithm is tested on the mineralogical diversity Humboldt crater in order to validate it. Multiple pure crystalline plagioclase occurrences were detected in Humboldt crater's central peak, whereas olivine and spinel occurrences possibly linked to a plutonic event were detected in the walls of Humboldt crater.

In chapter 2, we investigate the central peaks and peak rings of 36 craters allegedly sampling material originating between +10 and -20 km around the crust-mantle interface. Our analysis points to the existence of lateral heterogeneities at the crust-mantle interface depth. The vertical transition from crust to mantle material is not sharp, but rather seems gradual. Indeed, although the composition of pyroxene changes with depth from high-calcium to lower calcium contents, plagioclase was widely detected in craters allegedly sampling mantle material.

Chapter 3 shows that the anorthositic Feldspathic Highlands Terrane (FHT-a) crust does not become drasticallymore mafic with depth. However, data hint at a pyroxene compositional change with depth in the FHT-a crust, from high calcium to lower calcium contents. Our findings are in agreement with the recently proposed hypothesis that the lunar upper mantle is rich in low calcium pyroxene, rather than olivine.

Chapters 4 and 5 display how the algorithm developed during this thesis can be applied to provide key input for the mineral characterisation of landing sites for future lunar landings.

This work illustrates the use of remote sensing data on crater central peaks in order to constrain the shallow interior of the Moon. Remote sensing data can also be used to help locate which type of samples would need to be returned in the future from the lunar surface, in order to contribute to further elucidating the organisation of the lunar crust and upper mantle.